NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

RIP CURRENT/CUSPATE SHORELINE INTERACTIONS VIA VIDEO IMAGERY

by

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September 2005

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
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1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2005	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Rip current/cuspate Shoreline Interactions in Southern Monterey Bay			**5. FUNDING NUMBERS**
6. AUTHOR(S) John E. Woods III			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release ; distribution is unlimited			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

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The hypothesis that the mega-cusps on the beach are erosional features of rip currents was tested by cross-correlating the 2m beach contour obtained using GPS beach surveys with an alongshore video pixel intensity line. During a time of steady rip channel migration, it was found on average that the cusps lagged the rip channels by 50m with a maximum correlation near one. Assuming the system is in steady state, a response time of 14.7 days was obtained by dividing the lag distance by the average migration rate.

14. SUBJECT TERMS Nearshore Oceanography, Rip Currents, Cuspate Shoreline, Sediment Transport, Video Imaging			**15. NUMBER OF PAGES** 59
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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RIP CURRENT/CUSPATE SHORELINE INTERACTIONS IN SOUTHERN MONTEREY BAY

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND PHYSICAL OCEANOGRPHY

from the

NAVAL POSTGRADUATE SCHOOL
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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

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ACKNOWLEDGMENTS

Thank you to everyone who contributed to the massive effort to help me complete this thesis. The list is too long to name everyone, but I want to especially thank, Mark Orzech, because without him, not one MATLAB program would have been completed. I would like to thank, Ed Thornton, for all his guidance and devotion to teaching a 'rock' such as myself, and for the two great trips that introduced me to the nearshore oceanography world.. Thanks to the entire Naval Postgraduate School Oceanography department, especially, Rob Wyland, Keith Wyckoff, and Ron Cowen for keeping the data set moving forward. To my family and friends for putting up with me at my worse. And to my father who looked over me throughout the process. Thank you to all.

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I. INTRODUCTION

A. BACKGROUND

1. Rip Currents

The shoreline of Southern Monterey Bay is one of the world's best examples of a quasi-stable rip current system owing to abundant sand supply and near normal wave incidence (Thornton et al., 2005). Rip currents are approximately shore normal seaward directed jets that originate within the surf zone and broaden outside the breaking region (MacMahan et al., 2004). Rip currents can reach velocities of 1-2 m/s and are a major concern in the United States due to the large number of drownings associated with them. Over 100 drownings per year are attributed to swimmers being swept to sea by rip currents. More people fall victim to rip currents in the state of Florida every year than hurricanes, lightning, and tornadoes combined (Lushine, 1991; Lascody,1998). Understanding the dynamics and variability associated with the highly complex rip current system is a major task for scientists.

U.S. Naval forces are interested in understanding rip currents, and other nearshore currents to aid in the planning and execution of beach assaults. Both amphibious and special operations forces operate across the surfzone, so understanding and modeling direction and magnitude of currents is vital for successful mission planning and accomplishment. Mines drifting inside the surfzone are also influenced by rip currents. The ability to predict where mines may be drifting is crucial to securing a littoral battlespace.

Most field observations of rip currents have been coupled to the underlying beach morphology (Shepard et al., 1941; Aagaard et al., 1997; Short, 1999; Brander and Short, 2001; MacMahan et al., 2005; including others). A rip current cell generally consists of a feeder channel that is parallel to shoreline, which converges to a deeper rip channel that is oriented in an approximate shore normal direction (MacMahan et al., 2005). Attempts have been made to relate the scales of rip current morphology to the local wave climate, shoreline orientation, sediment size, and tidal conditions (Short and Brander, 1999). Correlations between all these factors have been consistently poor. Data collection

techniques until recently had been visual by eye only, and this was thought to be a factor of the poor correlations. Video imaging is a useful tool to characterize rip currents since it allows long-term data sets to be measured.

Rip spacing is determined by calculating the alongshore distance between two neighboring rip channels. Rip channel shapes are easily discernible from video imaging, and their variability is evident. Migration rates are quantified by tracking rip channel locations moving up and down the beach in the alongshore direction.

2. Beach Cusps

The dynamics between rip currents and beach cusps is not well understood, though they have been documented since the inception of rip current research (Shepard et al., 1941). Aerial photography suggests that rip channels are associated with the embayment of cusps. Figure 1 shows that rip channels are present at the center of each cuspsoidal embayment. It is hypothesized that beach cusps are responses to the rip current field and share similar morphological time and spatial scales.

3. Study Site

Monterey Bay, located about 100 km south of San Francisco, is a large, almost symmetric, embayment on California's central coast. It has a gently curving shoreline approximately 48 km long located in a microtidal, swell dominated coastal environment. The focus of this study is the Southern Monterey Bay littoral cell from Monterey to the Salinas River. Wave trains entering the Southern Monterey Bay experience considerable refraction as they pass over the Monterey canyon just offshore. The refraction bends the wave trains so that they approach the shoreline almost shore normal. This refraction also leads to a dramatic gradient of wave energy from the sheltered barred beach of Del Monte to the energetic, rip dominated shore of Marina State Beach (Holt, 2003). A small angle of incidence is the preferred environment for rip current development, which makes Monterey Bay a desirable natural laboratory. The nearshore morphology along Southern Monterey Bay is representative of a rhythmic transverse-barred beach incised by rip channels. The foreshore of the beach is relatively steep (1:10) with beach cusps O (35m),

flattening out to a low tide terrace (1:100) with quasi periodic, O (200m) incised rip channels, continuing with a 1:20 offshore slope (MacMahan et al., 2005). Rip currents are observed year round.

4. Objectives

The objectives of this thesis are to determine rip spacing, shape, and migration rates compared with wave measurements, and how mega-beach cusps are related to rip currents. Video images of a 2 km stretch of shoreline at Fort Ord, California are analyzed to measure rip channel location. Offshore directional wave measurements are refracted to the 10m contour at Fort Ord. The 2m beach contour is surveyed using Kinematic GPS mounted on an ATV to measure beach cusps.

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II. DATA

A. VIDEO IMAGING

The Naval Postgraduate School maintains four camera sites along the Southern Monterey Bay as part of the Naval Postgraduate School Nearshore Imaging System (NAPSIS). The four stations have varying capabilities (Table 1). The Stillwell Hall site, although the newest, currently has the best quality data set. This data is the most desirable, not only for its highest camera elevation, but also for the rip channel fields in the coverage area. The wave climate is energetic in the area, and tends to produce many well-defined rip channels.

Three different types of images are acquired every 20 minutes using the NAPSIS - snapshot images, time exposure images, and variance images. A snapshot image (Figure 2, upper panel) serves as a simple documentation of conditions, but offers little quantitative information. The most obvious feature of a snapshot is the foam of the breaking wave which shows up as white. Twenty-minute digital time exposures of the nearshore wave field (Figure 2, middle panel) average the location of the wave breaking to reveal a smooth band of white, which has been shown to be an excellent proxy for the underlying submerged rip channel morphology (Lippmann and Holman, 1989). Variance images (Figure 2 lower panel) help identify regions that have pixel intensities changing in time (like the sea surface), to distinguish them from those that may be bright but are unchanging (like the dry beach) (Aarninkhof, 1999).

Time exposure images are the most useful for nearshore morphology studies. Wave breaking is a function of depth. Waves break over shallower bars sooner since waves break at an apporoximate depth of 1.7 times their significant wave height (Thornton and Guza, 1983), and will break later over deeper trough areas where the wave breaking criterion is not met until closer to shore. A profile that is characterized by a series of bars and troughs will exhibit a concentration of waves breaking over the shallow depths of the bars, with little or no breaking over the deeper troughs (Komar, 1998). Bathymetry is inferred from images where areas of low pixel intensities (dark areas) are associated with deeper depths, and higher intensities (bright areas) occur in shallower

water or over bars (Figure 3). The locations of bright bands of wave breaking in time exposure images have previously shown to correspond well to the locations of submerged sand bars (Lippmann and Holman, 1989, van Enkevort and Ruessink, 2001). Similarly, gaps in breaking patterns correspond to topographic rip channels that incise a surrounding sand bar (Ranasinghe et al., 1999, Ranasinghe et al., 2004). Feeder currents for the rip channels can be seen in high quality images (Figure 3).

The oblique view video images are rectified to plan view images in order to perform quantitative analysis of the video data. Ground Control Points (GCPs) are required to solve the equations needed to rectify an image so that an object is known absolutely in both image and world coordinates (Holland *et al.* 1997). Ground Control Points can be either natural or man made accurately surveyed landmarks within the field of view of the cameras. A combination of these two points is used at most sites, and manmade GCP's have been installed at each location with known fixed GPS coordinates. Rectification allows the scene captured by a camera's lens to be transformed from image coordinates (U and V) into world coordinates (X and Y) (Holman 2000), and produces a plan view of the beach under the assumption that all imaged pixels lie in the plane of the ocean(Figure 3). The plan view is put in a coordinate system with the camera location as the origin. Obtained from a three camera system at elevation 10m and near to the survey area, Holland *et al.* (1997) calculated world coordinate errors of O(1m) for the rectified images. This is the same order of error by surveys using LIDAR (Sallenger et. al. 2003) and is extended to the NAPSIS (Holt, 2003).

The data set used for this analysis is from 6 November 2004 through 31 May 2005, from the solar powered, 2 camera system at the NAPSIS Stillwell Hall site. This is the time of winter storms when the largest changes in morphology are expected. The coverage is a 400m width of beach and surfzone in the Y (cross-shore) direction and +/- 1km in X (alongshore) direction. One ten minute time exposure image is rectified and stored every hour during daylight hours. Images from 0700 PST to 1800 PST (optimal daylight hours) were averaged to create one DAYTIMEX image for each day to provide a tide averaged characterization of bar morphology. Three mean pixel intensity lines were overlaid on each image, and the pixel intensities were plotted underneath each rectified image to aid the observer in determining rip locations. A total of 210 images were

analyzed over the time period. Image quality depends on weather conditions (visibility issues from fog or rain) and wave conditions (high waves break across the entire surfzone, Figure 4). During inclement weather, the entire surfzone is masked by the limited visibility, whereas during high wave events, the surfzone is visible, but the underlying features are washed out due to intense breaking over the entire bar. Data set quality control is discussed in the next section.

Distortion can be a problem with video imaging. As the distance from the camera increases, objects become distorted. During rectification, the distortion increases the error of the objects plan view location. Corrections for the distortion effects were made by comparing video and survey locations. Using the ATV as an object that can be seen relatively clearly in the images, 7 different locations were surveyed while the cameras obtained time exposure images. The GPS surveyed positions of the ATV were then compared to the (X,Y) plan view coordinates obtained from the cameras. Figure 5 shows the comparison, and how the errors increased as the ATV distance from the cameras increased. A linear correction was obtained by taking the difference in position obtained from the ATV and cameras and obtaining a slope and intercept from the linear fit line. This correction was then applied to the alongshore axis output from the cameras.

1. Rip Locations

Symonds and Ranasinghe (2000) used an alongshore line of pixel intensity within the surfzone to identify rip channels as troughs in the intensity. To aid the observer in discerning rip channel locations, 3 pixel intensity lines were overlaid on each rectified 'daytimex' image (Figure 6). The 3 pixel intensity lines were separated by 20 meters in the cross shore, while pixel intensities were calculated at one meter intervals alongshore. The 3 intensity lines are used to assist in the analysis of rip channel location as the rip channels often were slanted relative to offshore. Different intensity lines would sometimes need to be used on each image, since sometimes the closest to shore line was picking up the Stillwell Hall dune in the southward facing camera (Figure 6). It is assumed the deeper rip channels occur at the dark areas of the image where the waves break less. Distinct dips in intensity are visible, even when there is not an obvious channel present (Figure 7). Intensity variations are much more discernible numerically compared with visual estimates, especially when only subtle differences are present over

a broad area. Along with the images and intensity profiles, a movie that combined all 'daytimex' rectified images was used to aid the analysis of rip channel locations. This became quite useful during reset events and times of high variability. A reset event is described here as when the existence of rip channels changed, either emerging or disappearing, usually during a period of high wave energy (Holman et.al., 2005). One possible reset event during early February will be discussed in the results section.

Determining rip channel locations from video images is subjective. An efficient MATLAB script is used to select and store all (XY) coordinates of the rip locations chosen using a cursor on the video image. A second observer analyzed a 110 day period of the data to determine confidence on both the observed occurrence and locations of sampled rip currents. The purpose of this test is to assess the subjectivity in picking rip channel locations. Comparison was good as seen in Figure 8, where the circles depict one observer and asterisks the other. Only 3 rip channel occurrences were obviously disputed.

2. Stillwell Cusp and Dune Morphology

Large cusps, sometimes called mega-cusps, having alongshore lengths of 100-1000m, are characterized by seaward protruding accretion horns and erosive embayment cusps (MacWilliams, 2005). Stillwell Hall consistently has cusps present and they were surveyed 10 times using Kinematic GPS (KGPS) mounted on an ATV during the study period. A focus of this study is rip current interactions with the cusps.

The beach is surveyed by driving the ATV low on the beach near the water line and returning higher on the beach. The +2m contour is interpolated (extrapolated) from the beach survey lines measured approximately every 1m alongshore. The latitude, longitude, and elevation data are converted into vector form, with the positive y vector oriented in the alongshore direction pointed north and the x vector in the offshore direction. The mean curvature of the Monterey coastline is subtracted from the data to examine variations alongshore of the cuspate shoreline. An average, or generic, coastline was created by fitting splines to increments of the shoreline and matching the intercept and slope of adjoining end points of splined sections. The variations of the shoreline are the closest perpendicular point of the survey from the generic coastline (MacWilliams, 2005). The NAPSIS images are centered off this generic coastline since the location of

the camera site is known from GPS survey coordinates. The camera correction coefficient is also added to the (XY), output from the camera, compressing the data towards the origin. Using the camera location as the origin, cusp locations are compared to minimum intensities from the corrected daytimex image (Figure 9). The hypothesis that beach cusps are an erosional feature of rip currents is investigated by cross-correlating the 2m contour with the alongshore pixel intensities from video images.

B. WAVES AND TIDES

Wave and tide statistics are used for analysis of the rip current system. Tidal changes affect breaking wave characteristics over bars. Tidal elevations were obtained at 1 hours intervals from a tide gauge at Wharf #2 in Monterey. Hourly deep water wave statistics were obtained from a directional wave buoy approximately 27 NM west of Monterey Bay, which is owned and operated by the National Data Buoy Center. Time series of the nearshore incident wave field are required to examine the relationship between rip spacing and the incident wave forcing (Holman, et al, 2005)(Figure 10).

The dominant deep-water wave direction is from the Northwest, but the waves undergo significant refraction as they pass over the Monterey Canyon and approach the shoreline almost shore normal. Inshore (10m depth) wave height, Hs, peak period Tp, mean direction at peak period, Dm, and normalized Fourier directional coefficients (a_1,b_1,a_2,b_2) were provided by Bill O'Reilly for the study period using the spectral refraction model described by O'Rielly and Guza (1988). The accuracy of the refraction model predictions was assessed by comparing model output with local wave measurements. Comparisons were done for the spring of 2002 when a Datawell Directional-Wave Rider buoy was deployed at Marina State Beach in 18m of water. From the refracted directional spectra time series, significant wave heights, H_s were generated and compared from April to June of 2002. Figure 11 is a previous comparison by Holt (2003) that showed the model under predicted waves height measured at the buoy by as much as 50 percent. Problems with the model subsequently were corrected which

included a mismatch in frequency bands between model and measurements. The recalculated model wave heights and buoy measurements show good correlation (Figure 12).

The good correlation obtained in this comparison gives confidence in using nearshore predictions rather than the raw offshore buoy data. It is hypothesized that an estimate of the alongshore sediment transport, Q_s, determines rip channel migration rates and directions. Qs is obtained by (U.S. Army Corps of Engineers, 1996)

$$Q_s = KS_{yx}C_b$$

where the dimensional coefficient

$$K = 1290 \text{ m}^3\text{-s/N-yr}$$

The radiation stress component S_{yx}, is calculated from the refracted wave measurements.

$$S_{yx} = \rho g \; E \; Cg(\overline{f}) / C(\overline{f}) \sin\overline{\theta} \cos\overline{\theta}$$

where the

$$E = \frac{1}{16} \rho g H_s^2$$

and $\overline{f}$ and $\overline{\theta}$ are the peak frequency and mean wave direction.

The phase speed at breaking, C_b is given by

$$C_b = \sqrt{gh_b}$$

where the depth at breaking is related to the wave height at breaking, which is assumed equal to the wave height at 10 meters water depth,

$$h_b \cong \frac{H_{rms10m}}{0.42} \cong \frac{H_{10m}}{0.42}$$

The estimated sediment transport rate is compared with the rip current locations in Firgure 13. Positive Q_s values are associated with southward sediment transports. This is expected since the nearshore predicted wave directions were predominantly from the

north. Negative Q_s values are northward transport, that corresponded to times of southerly predicted wave directions (Figure 13, circles). Characteristics such as rip channel slope, variability and alongshore migration rates will be compared to alongshore sediment transport, Q_s.

The winter of 2004-2005 (Nov-May) displayed an average extreme wave climate. The largest wave event of the winter was a significant wave height of 6.2m on 11 April, 2005, which is almost exactly the expected one year return period wave height of 6.3m (Wyland and Thornton, 1991).

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III. RESULTS

A. RIP CHANNELS

Over the winter of 2004-2005 the spacings, shapes and migration rates of the rip currents at Stillwell Hall were constantly changing. Time-exposure movies linking together the entire data set allows visualization of the complex and unstable system.

1. Rip Channel Spacing

Rip current locations should not be considered daily events, but rather considered as long-lived coherent structures (Holman et.al., 2005). The locations were determined using both the rectified time exposure images and the corrected mean pixel intensity lines (see for example, Figure 9). The nearshore morphology in the Southern Monterey Bay exhibited a changing beach state as described by Wright and Short (1984). From the beginning of the data set to the end of January/early February the beach was a transverse-barred beach (TBB) and then transitioned to a longshore-barred-trough beach (LBT). This is seen in the location data (Figure 10) where 6 rip channels are consistently present between 0 and -1000m alongshore then seemingly disappear into two further spaced rips. Rip spacing increases from 150m to over 500m over the course of 2 days. Time exposure images also confirm the beach state change. Figure 14 demonstrates that rip cells did not disappear during high wave energy events, but rather changed shape and size, and or, combined into one larger rip current. The rip current system was continually changing during this period of time.

Alongshore rip spacing statistics were determined as the alongshore distance between adjacent rips for days when rip currents existed (Holman et al., 2005). Spacing was divided into two populations to separate the different beach states. The first population is from 1 November to 31 January and the second is from 1 February to 31 May. The mean rip spacing is 173 and 258m respectively. This rip spacing distributions are shown in Figure 15. The distributions are highly skewed and qualitatively similar to a log normal distribution, which is a similar result that was found for a much longer data set by Holman et al. (2005).

The coefficient of variability was computed, which is equal to the standard deviation divided by the mean spacing. Again this was separated into two populations representative of the two different beach states, and was computed to be 0.53 and 0.58 respectively. Holman et al. (2005) analyzed four years of rip current spacing at Palm Beach, Australia and measured a coefficient of variation of 0.39. These relatively large coefficients of variation emphasize that the rip current spacings are far from periodic.

2. Rip Migration

Rip current migration is hypothesized to be a function of the rate of littoral sediment transport, Q_s, which is a function of wave intensity and longshore current. During this study period, the rip channels moved both north and south at different times. A period of persistent southward movement was observed from 1 December through 21 December 2004. The rip movements during this time are outlined in Table 2 and show a southward migration of the rip channels of approximately 3 m per day. Time exposure movies also confirmed that the rip channels migrated southward during this time period.

The direction of migration qualitatively conformed to the direction of sediment transport for three distinct periods (Figure 13). A consistent southward migration occurred from 12 November to 7 December while Qs was predominantly southward (positive). From 1 March to 29 March, the rip channels rapidly migrated northward during a short period of northerly Qs values. Then after some readjustment back towards the south through April, the sediment transport rate decreased to almost zero, and the rip channels responded by maintaining constant positions.

3. Rip Channel Orientation

The rip channels demonstrated variable orientation with some perpendicular to shore and others slanted either upcoast or down coast. The location of the pixel intensity minimum varies with distance offshore if the rip channel is slanted. The slant of the rip channels were determined by computing a linear least-square fit to the three intensity minimums at x and y positions for each rip current (Figure 16). A positive slope infers that the rip channel points northward, whereas a negative slope is a southward slanted rip channel. The analysis for only the north facing camera starting in early December, 2004. This period showed a highly complex rapidly changing system. The rip channels started on yearday 346 southward tilted and slowly became northward tilted by yearday 356.

The sediment transport was initially to the north, opposite to the southward rip channel tilt. Sediment transport became southward (positive) on yearday 356 and the rip channels responded by tilting northward in the opposite direction of the transport.

Comparing video images and movie loops revealed that the base of the rip channels (nearest to shore) moved more rapidly than the head (furthest offshore) of the rip channels causing the rip channels to tilt. The base of rip channels migrate more rapidly as the sediment transport is greater in shallow water, causing a tilting in the opposite direction of the sediment transport (Figure 17). The gradient in alongshore sediment transport in the cross-shore is responsible for the shape of the rip channels. Periods of rapid changes in transport, such as what is shown in Figures 16 and 17, are the probable cause for the C shaped rip channels.

B. STILLWELL HALL BEACH CUSP/RIP CHANNEL INTERACTION

The hypothesis that beach cusps are an erosional feature of rip currents is investigated by cross-correlating the 2m beach contour with the alongshore pixel intensities. The period for the first 6 beach surveys from 12 November through 21 January was a time of well defined mega-cusps, and provide the most interesting comparison between the rip channel field and the 2 meter contour ATV survey data. This was also a time of steady rip migration to the south with well defined rip channels. Cross-correlations were performed between the 2m survey data and the corrected mean pixel intensity line at 180m. The correlation covered the area of the northward camera from -200m to -1000m as the rip field was well established in the area. As an example, performing the cross-correlation on 12 December (Figure 18) shows a maximum lag of -50m and maximum correlation of 0.57. A southward migration is evident when tracking the rip channels alongshore position versus time from 'daytimex' movies. Therefore it is determined that the rip channels are migrating to the south and the cusps are lagging the rip channels by approximately 50 m. The correlations of all 6 surveys were summed and averaged to obtain an average correlation for the surveys (Figure 19). The averaged correlation had a maximum lag of 47m and a maximum correlation at 0.97, which is significant with 95% confidence.

Assuming steady state conditions with constant migration, an approximate response time of the cusps to come into equilibrium with the rip migration is calculated by dividing the lag distance by the migration rate per day (3.2m/day). This gives a response time of 14.7 as the rate at which the cusps fully adjust to the rip channels migration.

IV. CONCLUSIONS

The interactions between rip channels and mega-cusps were analayzed for the winter of 2004-2005 in Southern Monterey Bay. Determining rip channels from video images is becoming an accepted method for understanding rip channel morphodynamics. Extracting mean pixel intensity lines from rectified plan view images at several cross-shore locations assists observers by giving both a visual and numerical format to locate the center of rip channels. However some subjectivity still occurs for locating the center of the rip channel. A simple MATLAB script was created to allow for an analyst to efficiently and consistently determine rip channel locations from video images. Time elapsed movies also aided the determination of rip current morphology. These two tools allowed for a comprehensive study into rip channel behavior over the study period.

An unexpected result was the beach appears to have changed states from a transverse barred beach (TBB) to a longshore bar trough state (LBT) during the study period. As a result data set was divided into two sections: NOV-FEB (TBB) and FEB-JUN (LBT).

Rip channel statistics for spacing and migration were determined. The mean rip spacing for the TBB state was 173 and the mean rip spacing for the LBT was 258m. Spacing in the southward facing camera was much more consistent than the northward facing camera, with average spacing consistently being approximately 200m. The northward facing camera picked up the beach state change and had an increased rip spacing to approximately 600m.

Directional wave spectra measured at the offshore NOAA buoy in deep water were refracted to the 10m depth contour at the actual study site. An estimate of alongshore sediment transport, Qs was calculated using the refracted wave data and compared to the rip characteristics.

The hypothesis that rip channel migration is due to alongshore sediment transport is qualitatively confirmed. Little or no migration occurred when Qs values were close to zero. Migration rates were calculated over a three week period during a time of rip mobility. Average migration rates were 3.2m per day and in a southward direction.

The rip channel orientations were constantly changing. Three distinct rip channel shapes were common: straight, slanted, or C shaped. At times all three types of rip channels were present within a 500m stretch of shoreline. Individual rip channels would also undergo transformation between all three types. The variability in rip channel orientation and shape led to difficulties in determining where the center of the rip was located. The slope of rip channels was determined by a least-square fit to the 3 pixel intensity line minimums for each rip channel. The rip channels tended to slant in the direction opposite of sediment transport, since the rip channels migrated more rapidly at their base (nearest to shore) and more slowly offshore. This results in the tilt of rip channels being opposite to the sediment transport direction.

The hypothesis that the mega-cusps on the beach are erosional features of rip currents was tested by cross-correlating the 2m beach contour obtained using GPS surveys with an alongshore video pixel intensity line. During a time of steady rip channel migration , it was found on average that the cusps lagged the rip channels by 50m with a maximum correlation near one. Assuming the system is in steady state, a response time of 14.7 days was obtained by dividing the lag distance by the average migration rate. The two week response time of the cusp suggests that surveying the beach every two weeks is not sufficient.

Figure 1 Aerial photograph showing cuspsoidal embayments centered on rip channels.

Stilwell Fort Ord Camera 2 snap: Fri Nov 19 1904GMT 2004

Stilwell Fort Ord Camera 2 timex: Fri Nov 19 1904GMT 2004

Stilwell Fort Ord Camera 2 var: Fri Nov 19 1904GMT 2004

Figure 2 Overview of NAPSIS image types from top to bottom snapshot, time exposure, variance image.

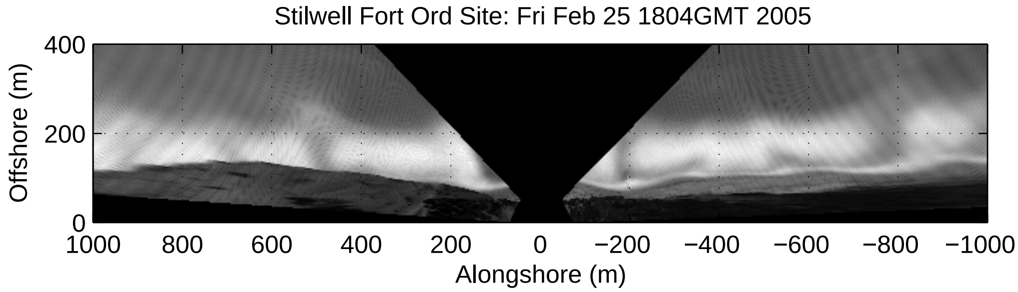


Figure 3 Plan view after image rectification. Real world coordinates with the camera location as the origin. Bathymetry is inferred as deeper depth are areas of less breaking (dark areas) and shallower depths are areas of more intense breaking (white areas).

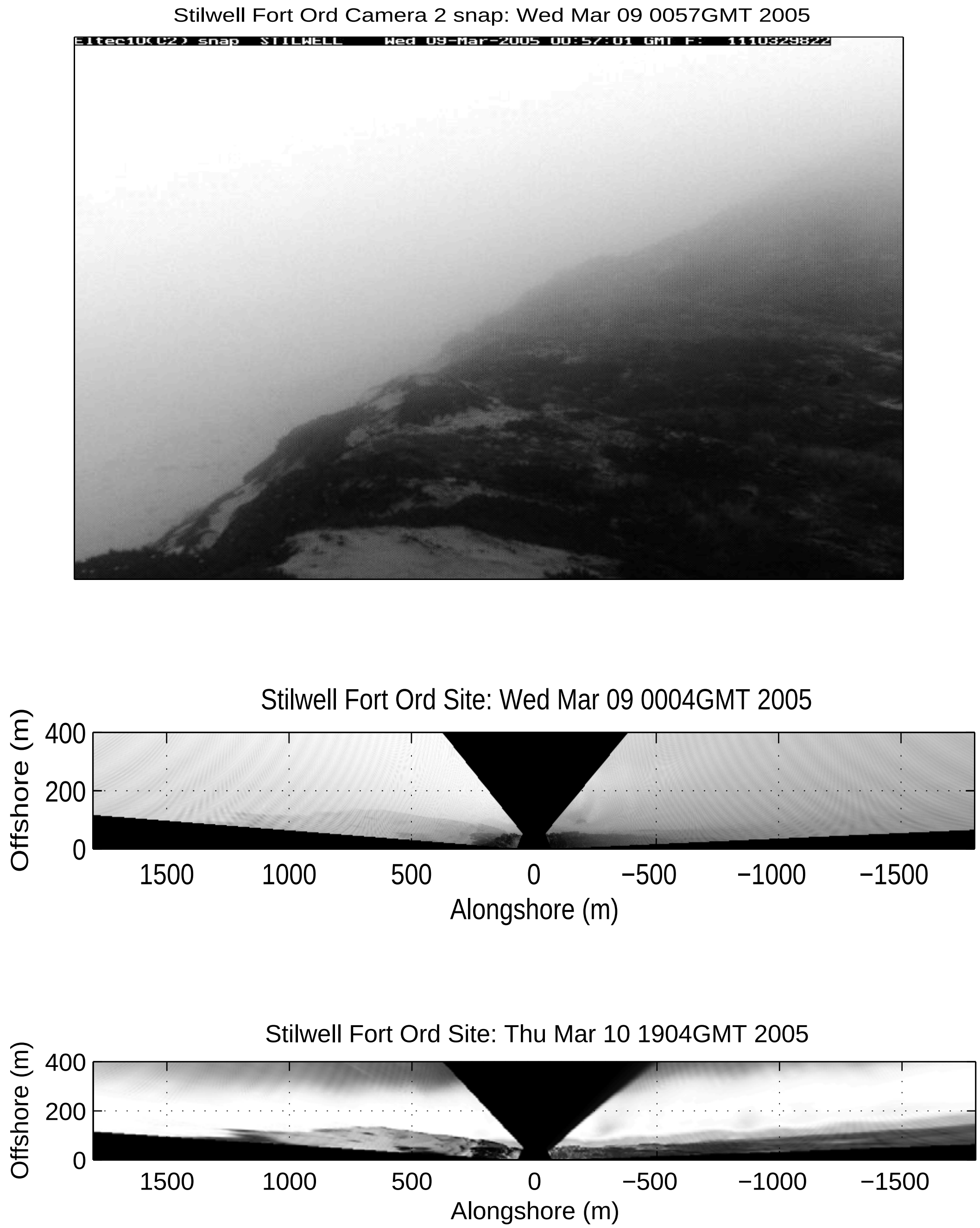


Figure 4 Weather effects on images. Fog deteriorates image quality and masks nearshore processes (upper, middle panel). High wave energy makes image appear as 'washed out' with intense breaking occurring across bars further offshore than normal due to the increased wave heights (bottom panel).

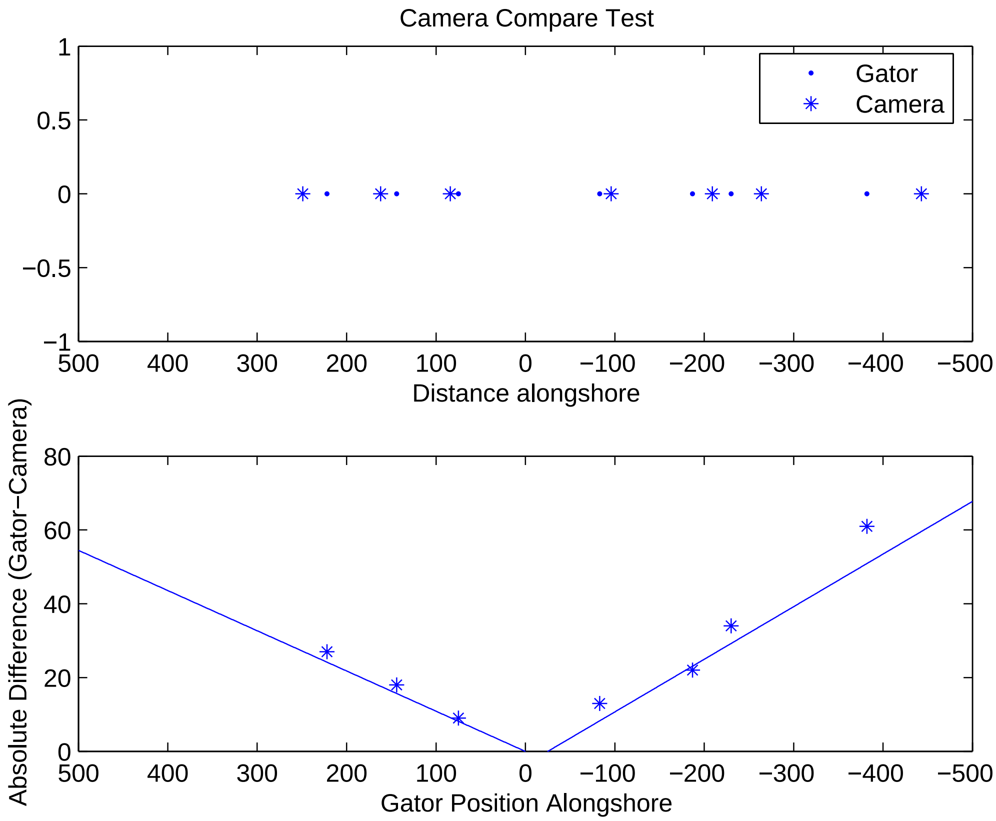
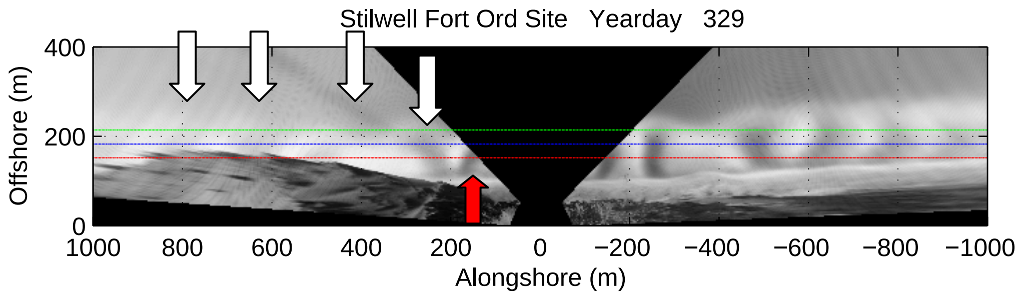


Figure 5 Camera comparisons to obtain corrections for distortion. Camera location is at the origin. As the gator moved away from the camera the error, (Gator position-Camera 'expected' position) increases. Correction values for slopes and intercept were obtained from linear regressions.



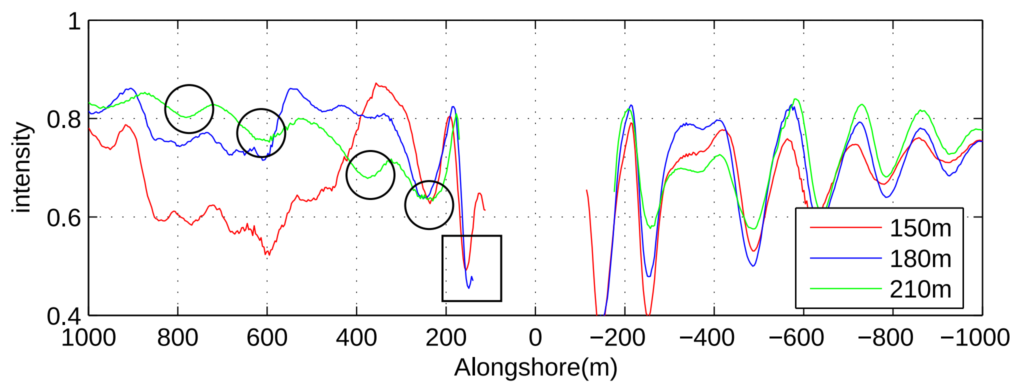


Figure 6 Dune interaction with intensity lines. Notice the southward facing camera, both the 150 and 180m intensity lines depict intensity changes due to dune interaction, not rip channel bathymetry. The 210m line depicts the 4 actual rip channels (circled and white arrows), but misses the nearshore rip channel that the 150m and 180m line does sense (boxed and red arrow)

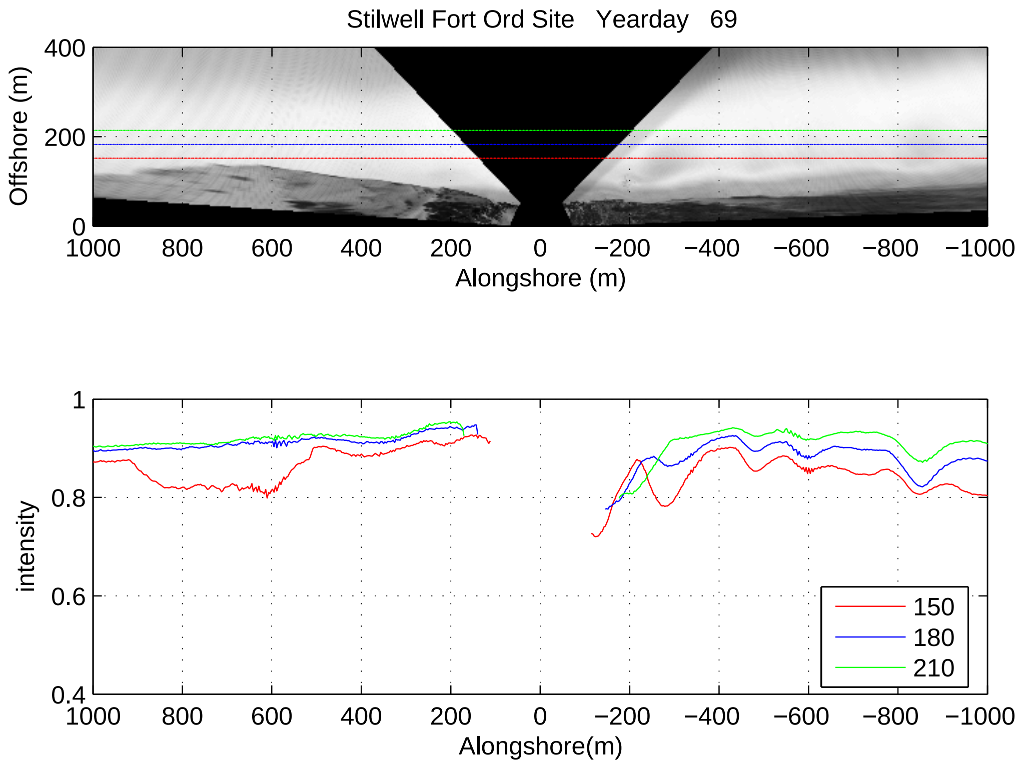


Figure 7 Washed out figure still showing rip channels in the mean pixel intensity lines. Notice dips in intensity at -500m,-700m,-600m, and -900m alongshore, with rip channels difficult to discern in the rectified image.

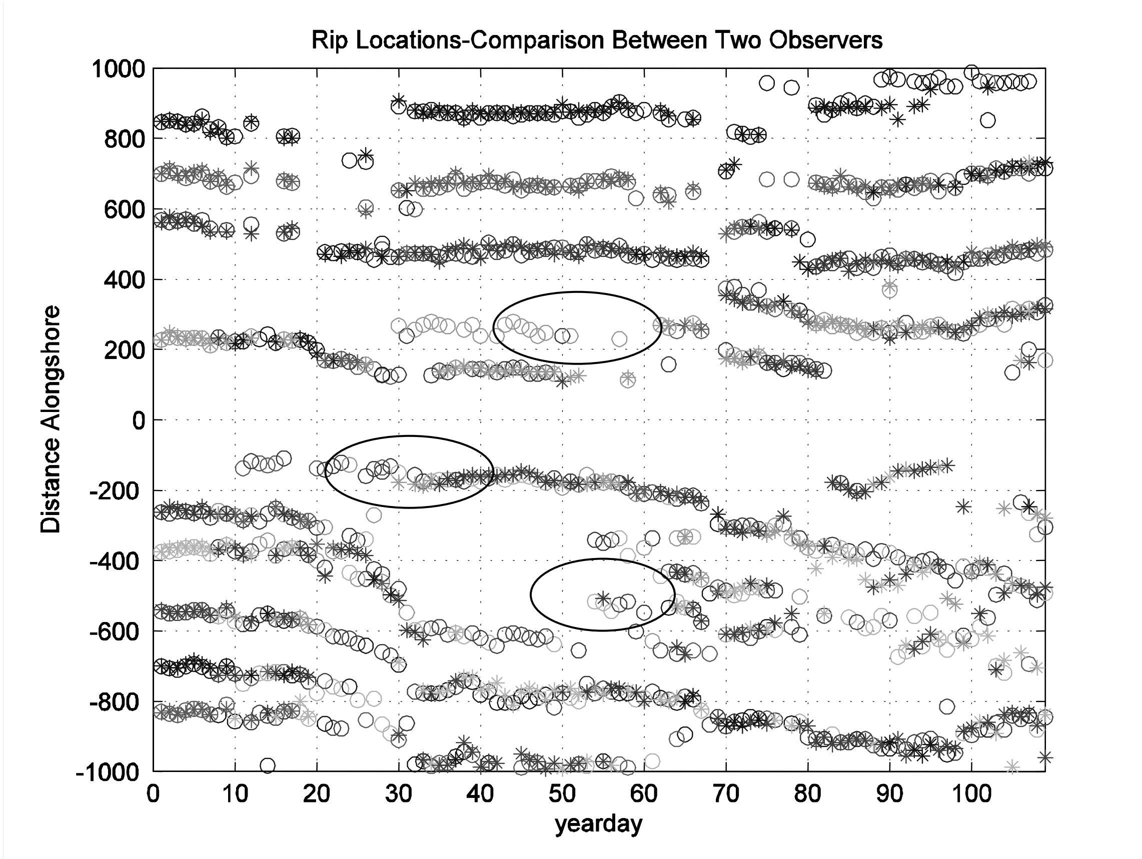


Figure 8 Comparision of rips locations between 2 observers. Good agreement was obtained with major discrepancies on only 3 occasions (circled).

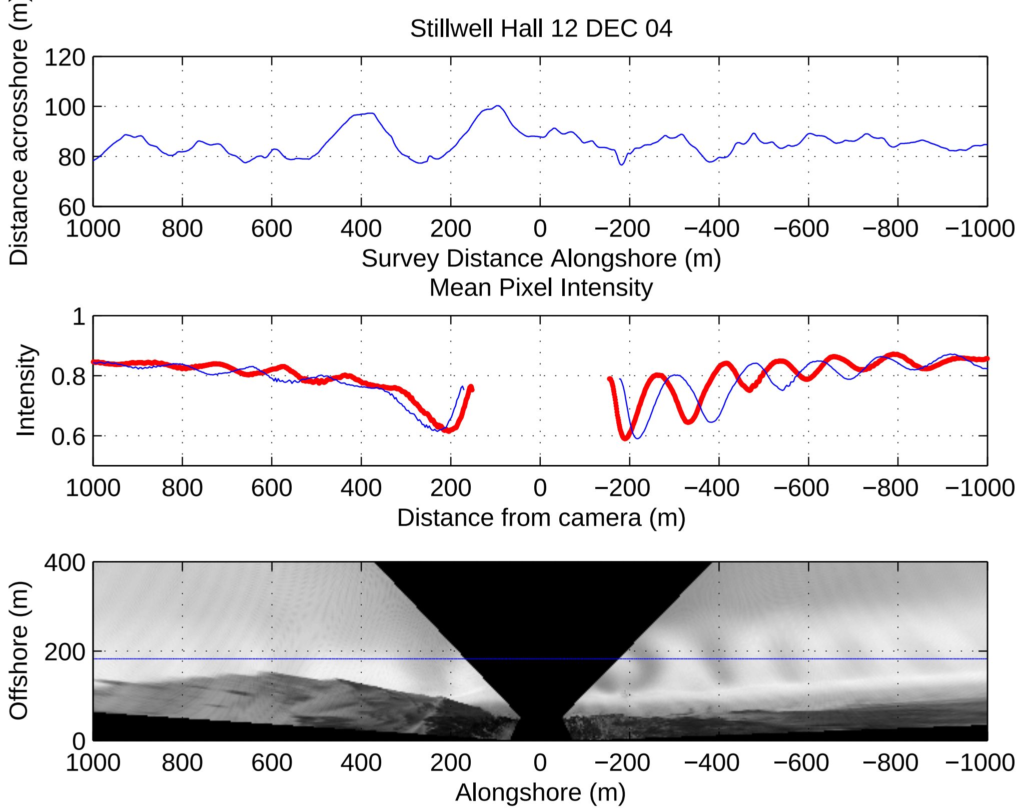


Figure 9 Data used for correlation between ATV survey data and mean pixel intensity line is 2m contour data from ATV survey. Middle panel is mean pixel intensity line at 180m before camera correction (blue line) and after correction (red line). Bottom panel is a daytimex image for corresponding day.

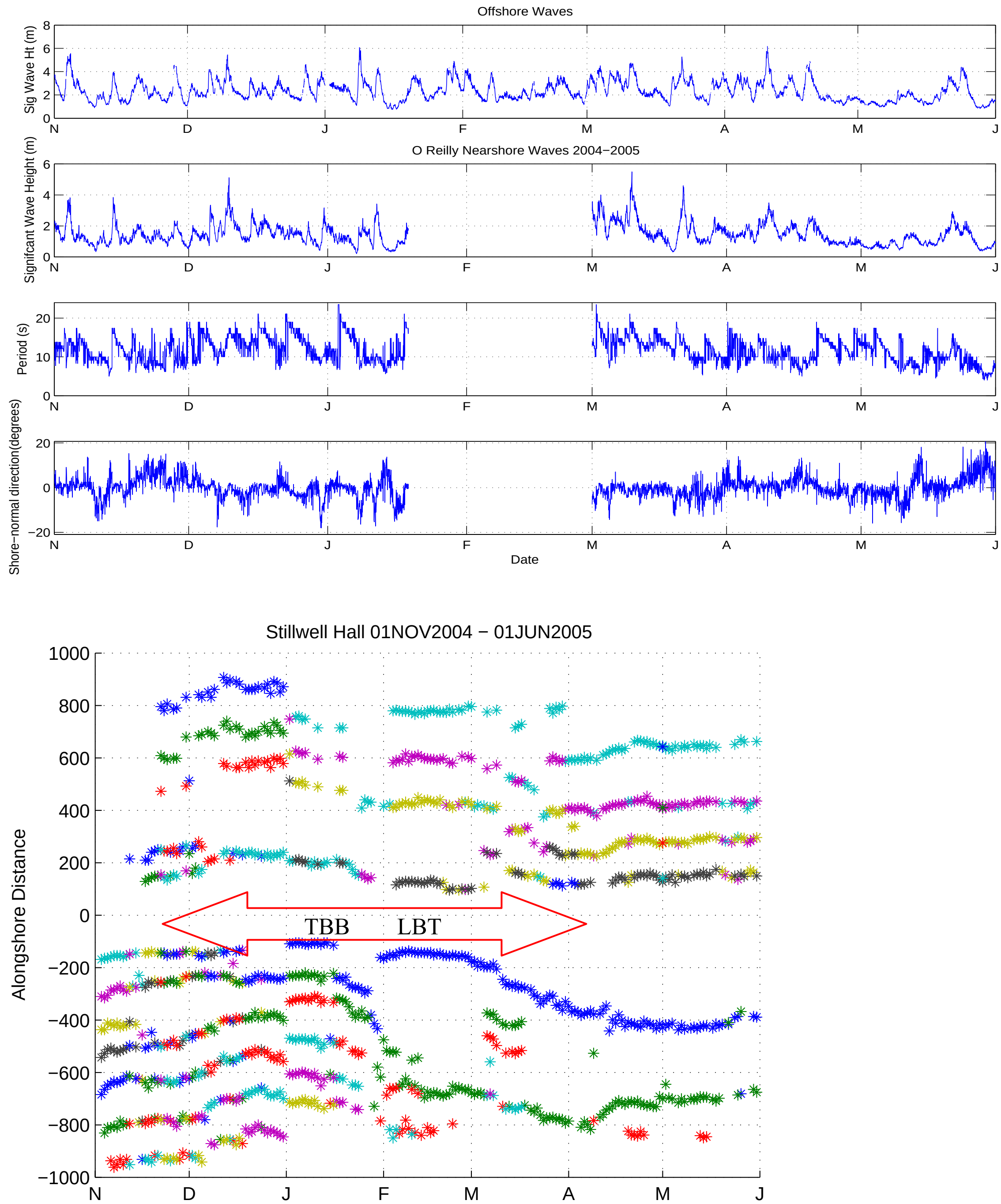


Figure 10 Significant wave heights offshore (top panel) and significant wave height (second panel) mean wave period (third panel) and mean wave direction relative to shore normal (third panel) at 10m depth offshore Fort Ord. Nearshore predictions are from O'Reilly Spectral Refraction Model. Break in data set was caused by interruptions in data from offshore buoy 46042. Bottom panel is rip locations vs. time during study period.

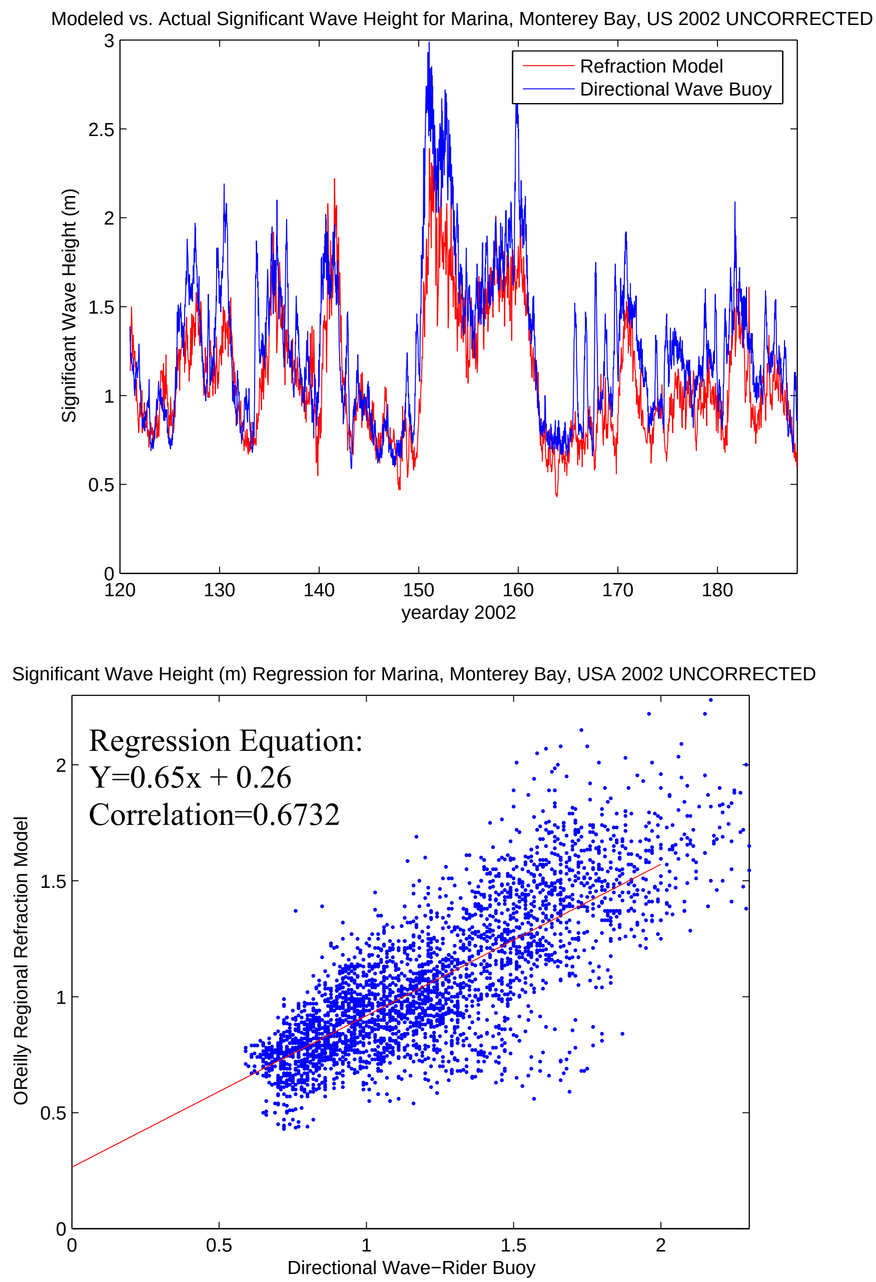


Figure 11 Uncorrected Marina Hs Comparisons from 2002. Linear regression between model and buoy (bottom panel) showing Hs was underestimated by 50-60% (top panel)(Holt, 2003).

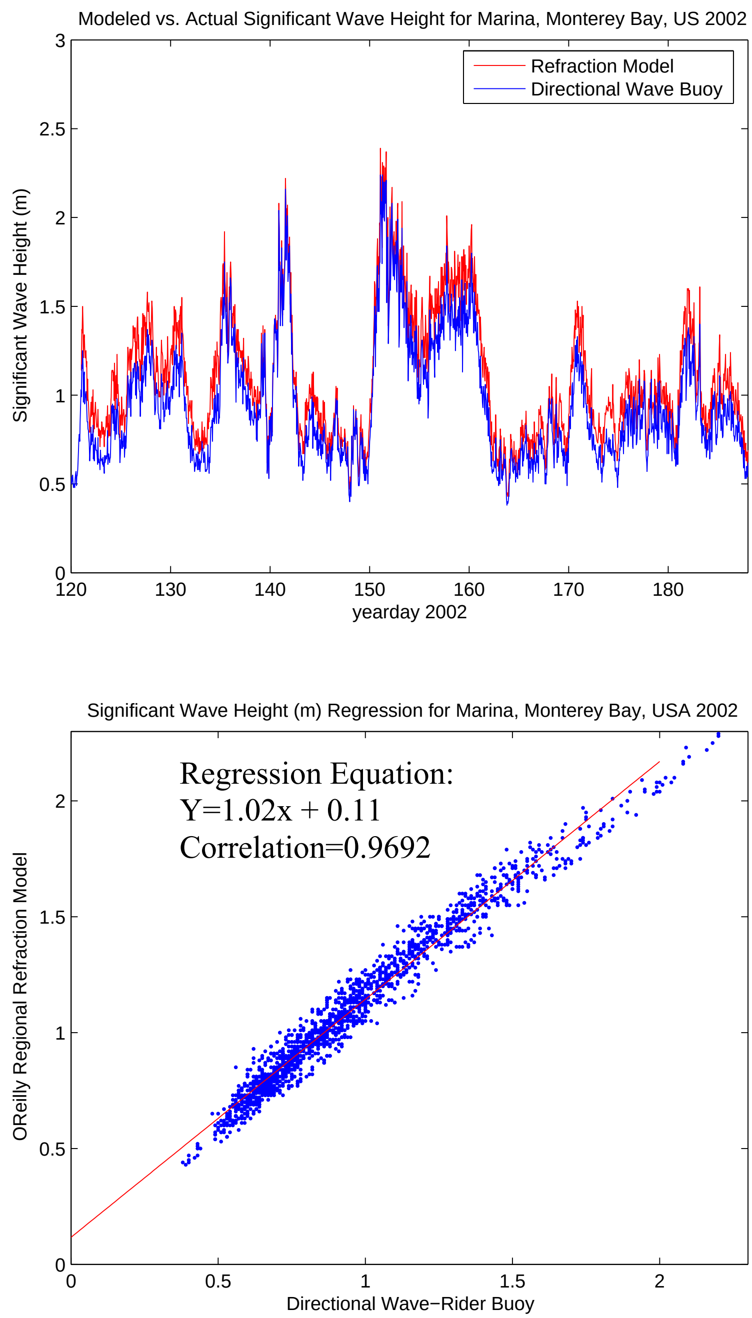


Figure 12 Corrected Marina Hs Comparisons from 2002 (top panel). Linear regression between model and buoy shows good agreement (bottom panel).

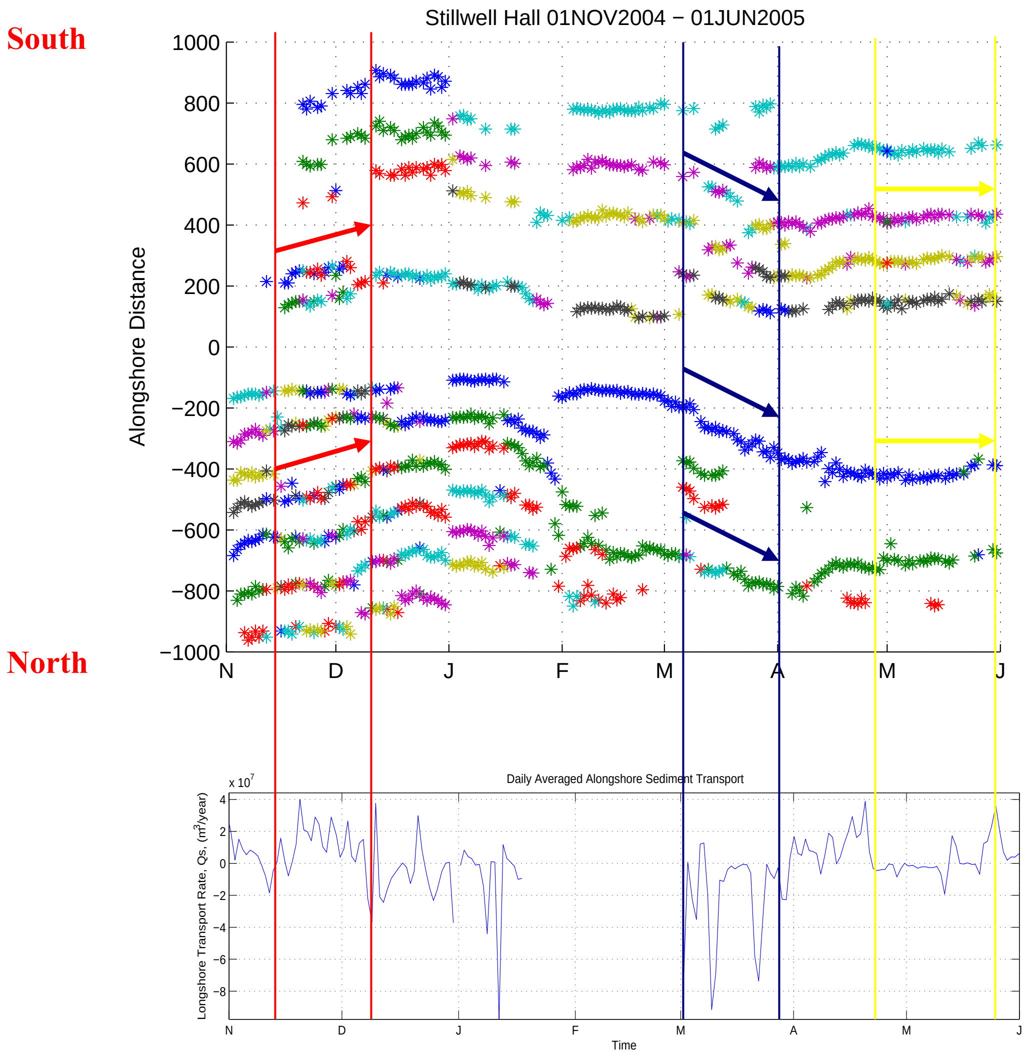


Figure 13. Rip locations vs. Time (Top Panel). Daily averaged wave direction at Tp (Middle Panel) Daily averaged alongshore sediment transport, Qs (Bottom panel). Three distinct period of qualitative direction of migration conforms to direction of transport (Qs). Positive (South migration) from 12 November to 7 December; Negative (North migration) from 1 March to 29 March; No transport (Zero migration) from 29 March to 29 May.

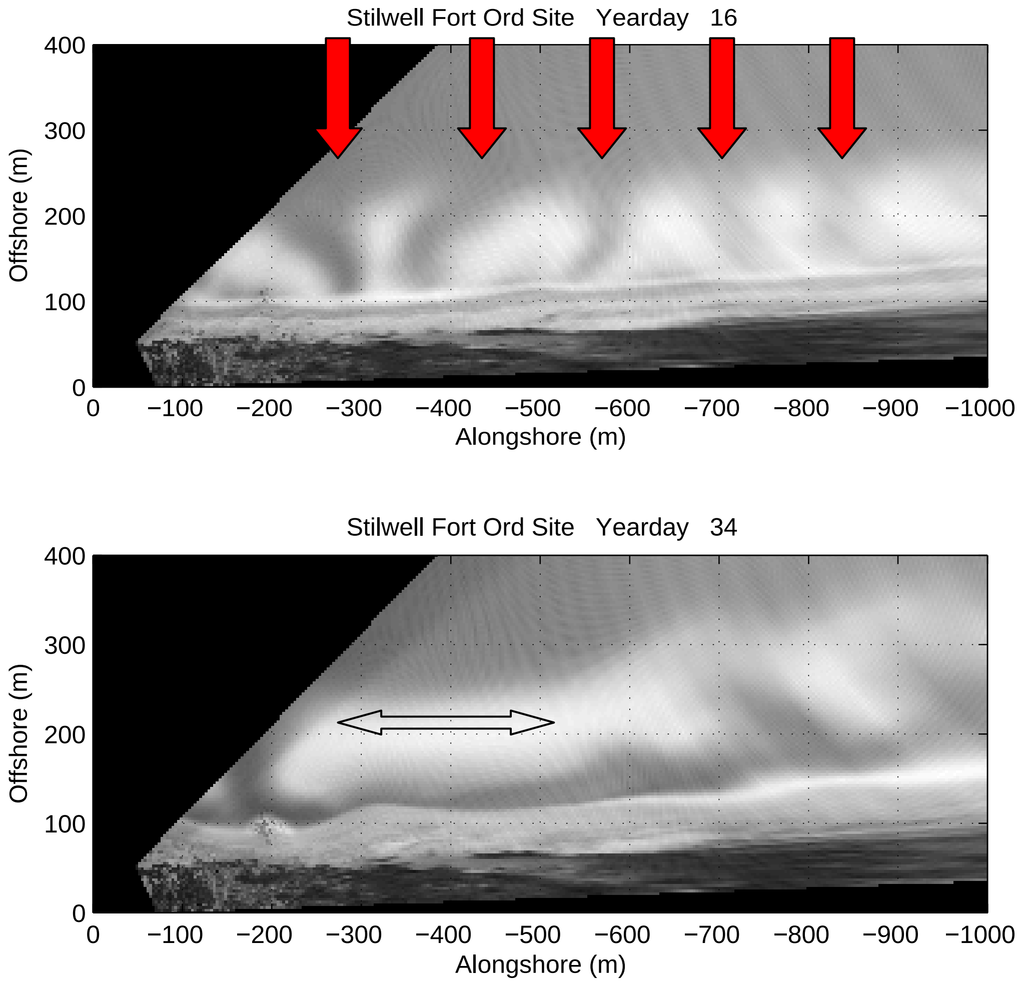


Figure14. Rectified images showing morphology state transformation. Top image show 5 transverse bars with rip channels (arrows). Beach changed from transverse barred-beach (TBB) to a longshore-bar-trough (LBT) state (Bottom Panel).

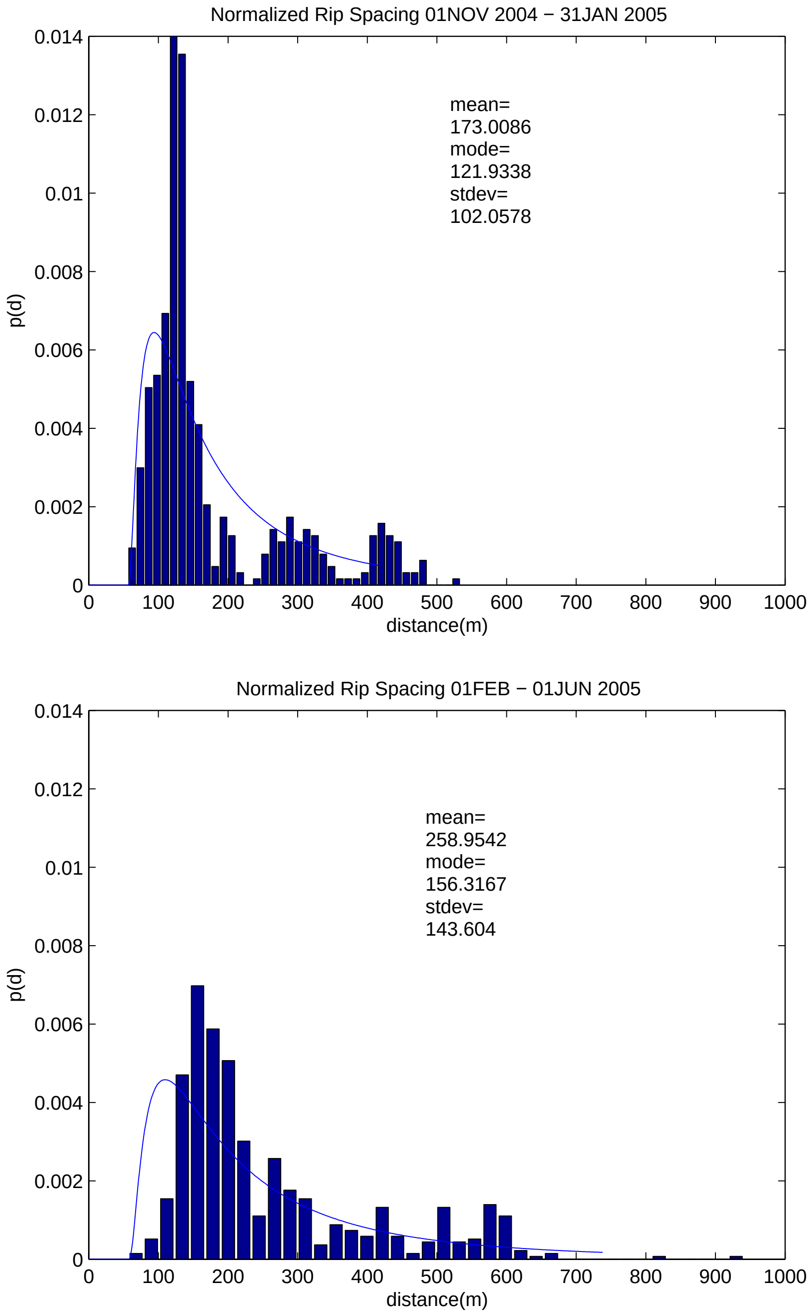


Figure 15. Rip channel spacing histogram. Rip spacing while beach exhibited a (TBB) state, mean = 173m (top panel). Increased spacing during a more LBT state, mean = 258m (bottom panel).

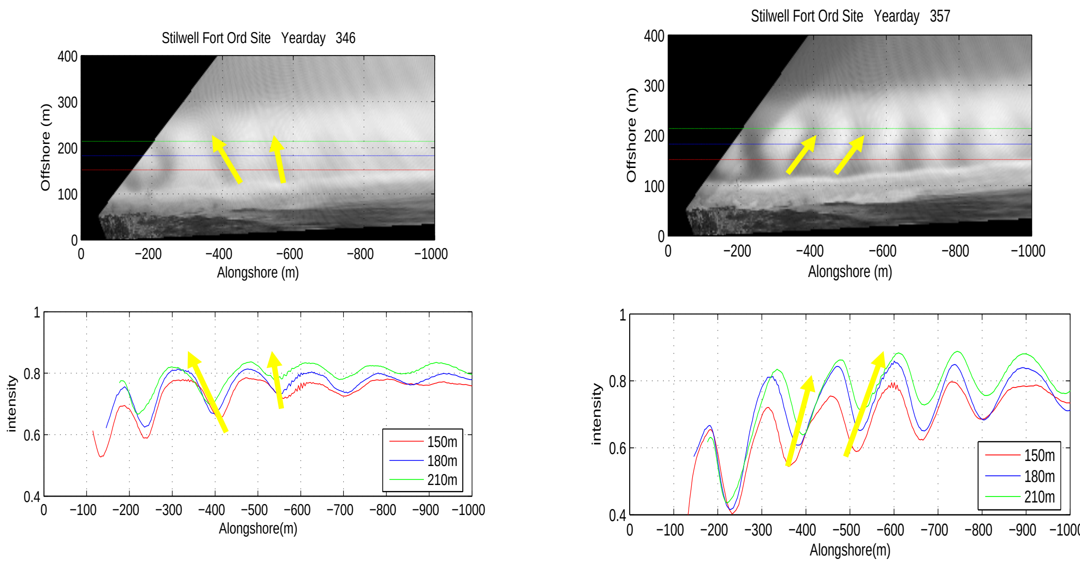


Figure 16. Rip channel slopes determined from mean pixel intensity lines. The slopes are determined by a least square fit to the 3 different intensity minimums. Slopes are negative (south) on yearday 346 and positive (north) on yearday 357.

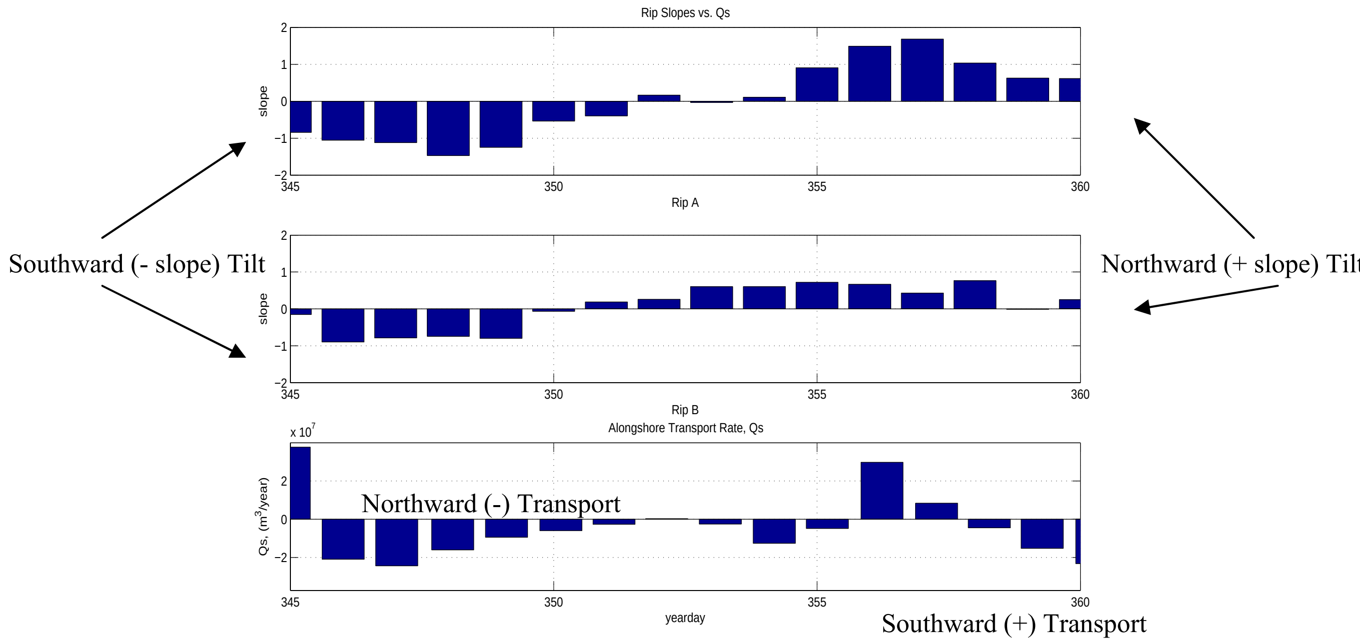


Figure 17. Rip channels A and B tilts from Figure 16 slopes vs. Qs. The rip channels tilt in the direction opposite to sediment transport. The base of the rip channels migrate faster than the offshore portion of the rip channel causing a tilting in the opposite direction.

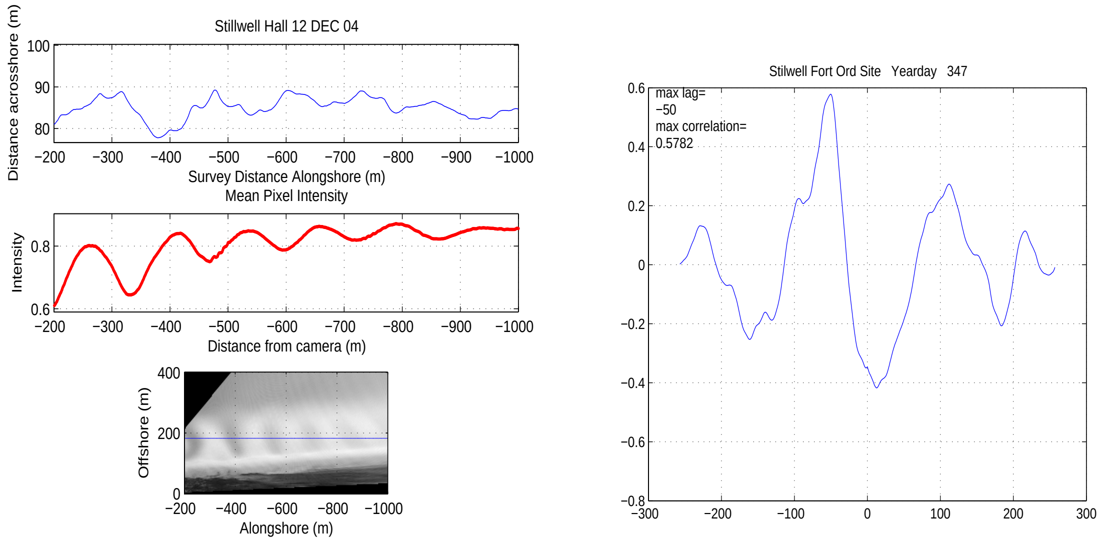


Figure 18. Cross-correlation (right panel) between 2m contour (top panel, left) and 180m pixel intensity line (middle panel, left) for 12 December.

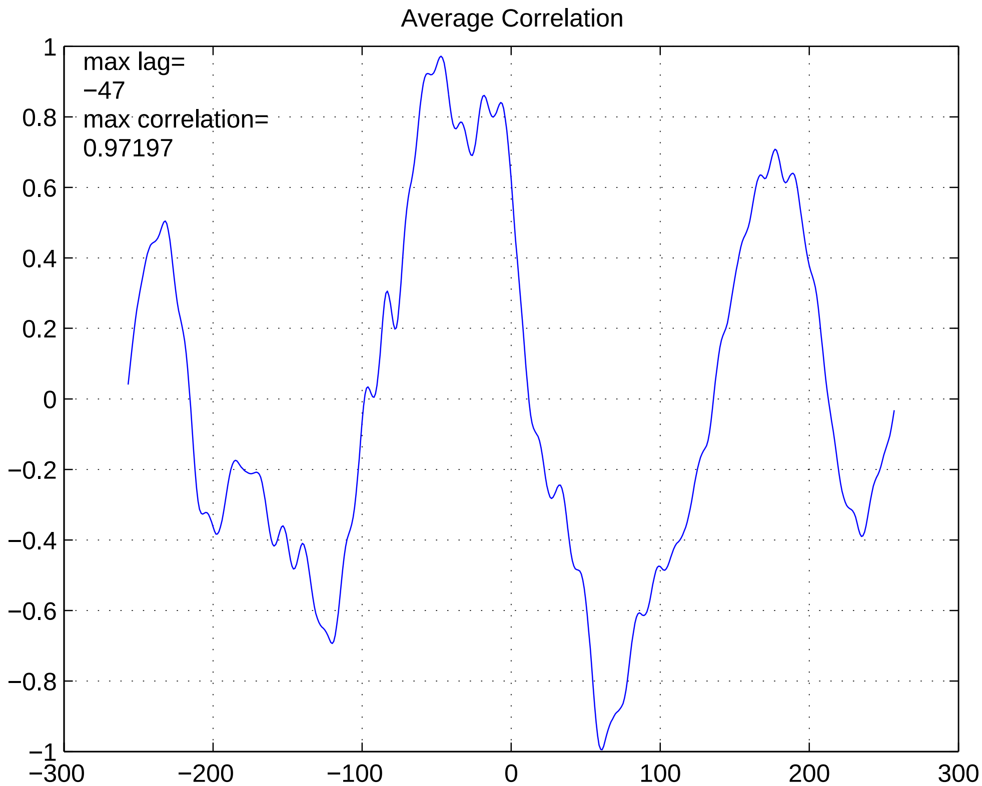


Figure 19. Averaged cross-correlation from 6 survey dates showing mega-cusps lag the southward migrating rip channels by 47m with a significant maximum correlation of 0.97.

	Del Monte	Sand City	Stillwell Hall	Marina
Lat/Long (deg/min/sec)	36 36’ 11.2”N 121 52’ 19.9”W	36 36’ 8.6”N 121 52’ 22.2”W	36 39’ 46.5”N 121 49’ 15.2”W	36 41’ 59.3”N 121 48’ 32.6”W
Alongshore/Crossshore Dist(m) generic coastline	1,523m/-72.5m	3,663m/-73.4m	9,691m/-71.3m	13,9125m/-59.3
Elevation above MSL(m)	16.5m	18.7m	38.9m	22.1m
Cameras(#, type)	1/Eltec-miniHiPerCam camera	2/Eltec-miniHiPerCam camera	2/Eltec-miniHiPerCam camera	5/Sony DC-50 Video camera
Data Set	DEC2004-Present	APR2001-Present	NOV2004-Present	OCT2002-Present

Table 1. NAPSIS Capabilites. Alongshore distance measured from Wharf #2 along the generic coastline. Crosshore distance is calculated from the waterline back towards the beach. Elevation is surveyed from mean sea level.

	01DEC2004 alongshore location	21DEC2004 alongshore location	Change in alongshore location	**Migration Rate (m/day) South**
Rip 1	-391	-339	52m	**2.5 m/day**
Rip 2	-516	-451	65m	**3.0 m/day**
Rip 3	-663	-590	73m	**3.5 m/day**
Rip 4	-798	-715	83m	**3.9 m/day**

Table 2. Rip migration of 4 rip currents over a 3 week period. Average migration rate =3.2m/day southward

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